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Pronation Reveals a Heterogeneous Response of Global and Regional Respiratory Mechanics in Patients With Acute Hypoxemic Respiratory Failure

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OBJECTIVES: Experimental models suggest that prone position and positive end-expiratory pressure (PEEP) homogenize ventral–dorsal ventilation distribution and regional respiratory compliance. However, this response still needs confirmation on humans. Therefore, this study aimed to assess the changes in global and regional respiratory mechanics in supine and prone positions over a range of PEEP levels in acute respiratory distress syndrome (ARDS) patients.

DESIGN: A prospective cohort study.

PATIENTS: Twenty-two intubated patients with ARDS caused by COVID-19 pneumonia.

INTERVENTIONS: Electrical impedance tomography and esophageal manometry were applied during PEEP titrations from 20 cm H_2O to 6 cm H_2O in supine and prone positions.

MEASUREMENTS: Global respiratory system compliance (Crs), chest wall compliance, regional lung compliance, ventilation distribution in supine and prone positions.

MAIN RESULTS: Compared with supine position, the maximum level of Crs changed after prone position in 59% of ARDS patients ($n = 13$), of which the Crs decreased in 32% ($n = 7$) and increased in 27% ($n = 6$). To reach maximum Crs after pronation, PEEP was changed in 45% of the patients by at least 4 cm H_2O. After pronation, the ventilation and compliance of the dorsal region did not consistently change in the entire sample of patients, increasing specifically in a subgroup of patients who showed a positive change in Crs when transitioning from supine to prone position. These combined changes in ventilation and compliance suggest dorsal recruitment postpronation. In addition, the subgroup with increased Crs postpronation demonstrated the most pronounced difference between dorsal and ventral ventilation distribution from supine to prone position ($p = 0.01$), indicating heterogeneous ventilation distribution in prone position.

CONCLUSIONS: Prone position modifies global respiratory compliance in most patients with ARDS. Only a subgroup of patients with a positive change in Crs postpronation presented a consistent improvement in dorsal ventilation and compliance. These data suggest that the response to pronation on global and regional mechanics can vary among ARDS patients, with some patients presenting more dorsal lung recruitment than others.

KEY WORDS: COVID-19; mechanical ventilation; prone position; respiratory distress syndrome; respiratory mechanics

Prone positioning and the use of low tidal volumes are the only nonpharmacologic respiratory interventions proven to reduce mortality in patients with acute respiratory distress syndrome (ARDS) (1). Due to

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KEY POINTS

Question: What are the global and regional mechanics responses induced by prone position and positive end-expiratory pressure (PEEP) in acute respiratory distress syndrome (ARDS) patients?

Findings: This prospective cohort study described that global respiratory system compliance changed in most ARDS patients (59%) after pronation and individualized PEEP titration. In addition, patients with increased global compliance (27%) presented the most heterogeneous ventral-dorsal ventilation distribution and significantly increased dorsal region compliance in prone compared with supine position.

Meaning: The variety of responses detected to pronation and PEEP in respiratory compliance suggests the need to individually assess the regional lung function to establish the body positioning mechanical effect.

severe hypoxemia observed in COVID-19 patients, prone positioning has been employed worldwide. Early publications report over 50% of intubated patients with severe COVID-19 were prone (2), a substantial increase in pronation use compared with previous cohorts (16–33%) (3, 4).

In many patients, prone position increases gas exchange by improving ventilation-perfusion matching (5–8). However, the response of the respiratory system compliance (Crs) to pronation in intubated patients is not yet fully elucidated (9–11). Indeed, previous studies have reported that the average Crs was unchanged after pronation (4, 7, 8, 12–14). Nevertheless, it is unclear if using the same fixed positive end-expiratory pressure (PEEP) values after pronation might have influenced these results.

Recently, Katira et al (15) assessed the effects of proning across a wide range of PEEP on respiratory mechanics and regional ventilation in a swine model of ARDS. The authors showed an average reduction of PEEP by 3 cm H_2O to reach maximum Crs after pronation. Prone position decreased the vertical pleural pressure gradient, thus, leading to more homogenous lungs and negligible regional compliance differences between dependent and nondependent lung zones.

No clinical study has carefully evaluated the effects of prone position and PEEP on regional ventilation and lung mechanics. Based on the findings reported by Katira et al (15), we proposed to determine the effect of supine and prone positions on global and regional respiratory mechanics by investigating the respiratory system at different levels of PEEP in intubated COVID-19 ARDS patients.

We hypothesized that the response of global respiratory compliance to pronation depends on the PEEP level set after body positioning and that changes in Crs after pronation (decrease or increase) alter regional ventilation and mechanics (15). To test our hypothesis, we performed a prospective cohort study. Electrical impedance tomography (EIT) and esophageal manometry (EM) were applied in 22 intubated patients with ARDS caused by COVID-19 pneumonia aiming to determine Crs, chest wall compliance (Ccw), regional lung compliance, and ventilation distribution changes during PEEP titrations in supine and prone positions.

MATERIALS AND METHODS

Study Design and Population

Data were prospectively collected from patients with respiratory failure due to severe acute respiratory syndrome coronavirus 2 pneumonia monitored by EIT and EM at Massachusetts General Hospital (MGH) and the Heart Institute (InCor) of the University of São Paulo. The prospective cohort data collection was approved by the local investigational review boards of the two participating centers (MGH: approval number 2019P001995, approval date: July 26, 2019; InCor: approval number 4001231, approval date: April 30, 2020). The procedures were followed in accordance with the ethical standards of the responsible committee of each hospital on human experimentation and the Helsinki Declaration of 1975.

Intubated patients were enrolled in the study cohort if they had $\text{Pao}_2/\text{Fio}_2$ of less than or equal to 200 mm Hg and needed a decremental PEEP trial per request of the ICU team caring for the patient in both the supine and prone positions, which were performed within 24 hours of each other. The decremental PEEP trial was performed with volume-controlled ventilation and PEEP decreasing stepwise by 2 cm H_2O from 20 to 6 cm H_2O (30 s for each step). A PEEP leading to maximum Crs was identified for each decremental PEEP trial. Patients were ventilated with protective tidal volume (4–8 mL/kg of predicted body weight, PBW) while receiving sedative and paralytic agents (see **Supplement Material**, http://links.lww.com/CCX/B254).

Data Collection

Regional lung ventilation and mechanics data were assessed using the impedance tomograph Enlight 1800 (Timpel Medical, São Paulo, Brazil). Pressure, flow, and volume from a pneumotachograph (Respironics Novametrix, Wallingford, CT) were recorded with the Enlight 1800 monitor. The recorded EM data, using the EM system Pneumodrive (Bionica, Recife, Brazil), were used to calculate Ccw. Global and regional respiratory mechanics were estimated in supine and prone positions during the decremental PEEP trial. The respiratory assessment was performed, on average, 2–4 hours postpronation, with arterial blood gas data available 1–2 hours after the PEEP titration. Detailed descriptions of the monitoring procedures are presented in Supplementary Material (http://links.lww.com/CCX/B254).

Data Analysis

EIT images were reconstructed and converted to a text file (.txt) for analysis using a software written in LabView (National Instruments, Austin, TX). A customized software written in R (R Foundation for Statistical Computing, Vienna, Austria) processed the signals from the EIT and EM. A respiratory cycle consisted of all data contained between the occurrence of two consecutive inspirations. Respiratory variable averages were computed based on 6–10 consecutive respiratory cycles at the end of each PEEP level during the decremental trial.

Respiratory Mechanics. Crs and Ccw values were calculated using multiple linear regression (see Supplement Material, http://links.lww.com/CCX/B254). The Crs response after pronation was quantified by the ratio of the maximum Crs obtained in the prone position to that obtained in the supine position ($\text{Crs}_{\text{PRONE}}/\text{Crs}_{\text{SUPINE}}$ ratio). Patients were stratified into three groups: Crs decreased ($\text{Crs}_{\text{PRONE}}/\text{Crs}_{\text{SUPINE}} < 0.90$), suggesting either an increase in lung overdistension or atelectasis, Crs-unchanged ($0.90 \le \text{Crs}_{\text{PRONE}}/\text{Crs}_{\text{SUPINE}} \le 1.10$), or Crs-increased ($\text{Crs}_{\text{PRONE}}/\text{Crs}_{\text{SUPINE}} > 1.10$), suggesting lung recruitment.

Crs was normalized by PBW to account for differences in height and sex for between-group comparisons (16) (e.g., a normalized compliance of 0.5 mL/cm H_2O/kg PBW would correspond to 35 mL/cm H_2O for a 70-kg patient).

Regional Lung Ventilation and Mechanics. The EIT image, a matrix containing 32 × 32 pixels, was divided into three gravitational regions of interest (ROIs) with similar height defined as ventral, central, and dorsal ROIs (e.g., the ventral lung region is the nondependent region of the lung in supine position and the dependent in prone position; **Fig. 1**). Regional ventilation distribution for each ROI was estimated from the impedance changes induced by ventilation (ΔZ_V) as:

$$\text{Ventilation ROI}(\%) = \frac{\Delta Z_{\text{V(ROI)}}}{\Delta Z_{\text{V(Global)}}} \times 100$$

where $\Delta Z_{\text{V(Global)}}$ is the change in ventilation in the whole EIT image. Regional ventilation distribution was normalized by the number of functional pixels presented in the predefined ROIs, defined as pixels with ΔZ_V greater than or equal to 5% of the pixel with maximum ΔZ_V, as a surrogate of the tissue content.

Regional compliance was calculated as $\Delta Z_{\text{V (ROI)}}$ divided by the driving pressure. In addition, we built pressure–volume curves using the changes in end-expiratory lung volume (EELV) measured during a decremental PEEP trial in supine and prone positions. Changes in EELV were scaled from arbitrary units to milliliters using the average slope (scaling factor) obtained from all PEEP steps during the decremental trial (17). For the EELV-PEEP comparison, we defined PEEP of 6 cm H_2O as the reference step for each position (i.e., EELV = 0 mL).

Lung overdistension was determined according to Costa et al (18) in supine and prone position. This method calculates the fraction of overdistended units in each image pixel, at each PEEP level, as the fraction of maximum compliance of each pixel.

Statistical Analysis

Normality was assessed by the Shapiro-Wilk test. Variables are presented as mean and 95% CI or median and interquartile range (IQR) when appropriate.

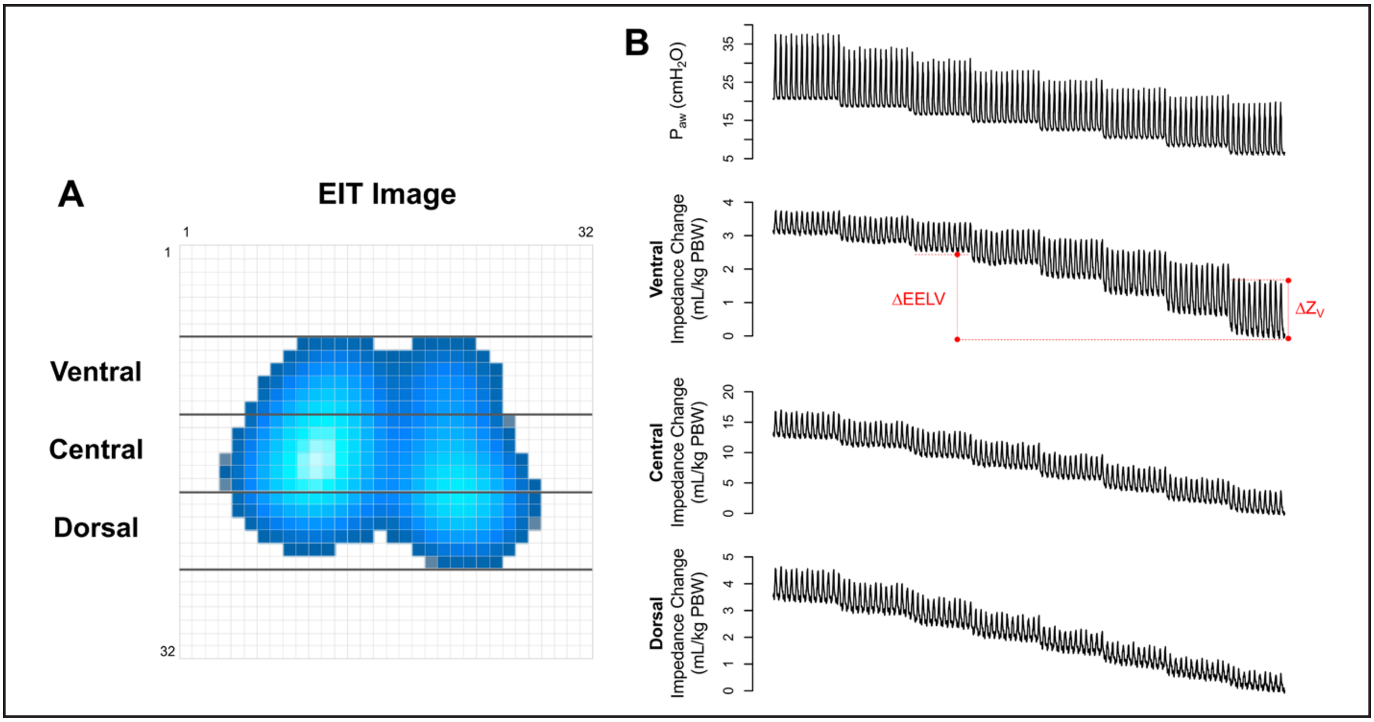

Figure 1. Analysis of regional lung ventilation and mechanics. **A**, Illustration of the electrical impedance matrix divided into three gravitational regions of interest (ventral, central, and dorsal). **B**, Airway pressure and changes in lung volume in the ventral, central, and dorsal regions along a decremental positive end-expiratory pressure trial. ΔZ_V = impedance changes induced by ventilation, EELV = end-expiratory lung volume, EIT = electrical impedance tomography, P^{aw} = airway pressure, PBW = predicted body weight.

Categorical data were presented as absolute and relative frequencies. The differences between supine and prone positions at different PEEP levels were tested using linear mixed models. Comparisons between body positions at the PEEP for maximum Crs (titrated PEEP) were analyzed by paired *t*-test or by Wilcoxon paired test, as appropriate. The analysis was conducted using R, version 3.6.2 (R Foundation for Statistical Computing). *p* values of less than 0.05 were considered significant.

RESULTS

From April 2020 to June 2021, 22 of 111 patients with COVID-19-related ARDS monitored with EIT entered in the study cohort (**Fig. E3,** http://links.lww.com/CCX/B254). Patient characteristics are shown in **Table E1** (http://links.lww.com/CCX/B254). The median age was 61 years (IQR 54–68), 11 patients (50%) were female, and their BMI was 32 kg/m^2 (IQR 29–35). After 24 hours of intubation, patients presented severe to moderate ARDS (median $\text{Pao}_2/\text{Fio}_2$, IQR = 107, 82–159 mm Hg), PEEP was 11 cm H_2O (IQR, 10–14), and Crs was 0.47 mL/cm H_2O/kg PBW (IQR, 0.41–0.52). The median time interval between intubation and our assessment was 3 days (IQR, 2–7). Noninvasive ventilation or a high-flow nasal cannula was applied in six patients (27%) before intubation. As expected, median $\text{Pao}_2/\text{Fio}_2$ was higher in prone compared with supine at the PEEP level leading to maximum Crs (**Fig. E4,** http://links.lww.com/CCX/B254, $p < 0.05$).

Changes in Global Respiratory Mechanics

After pronation and PEEP titration, maximum Crs showed a variety of responses. Crs decreased by more than 10% in seven subjects (32%) ("Crs-decreased" group), remained unchanged in nine patients (40%) ("Crs-unchanged" group), and increased by more than 10% in six patients (27%) ("Crs-increased" group), suggesting heterogeneous changes with either lung recruitment, lung overdistension, or Ccw in response to pronation and PEEP titration (**Fig. 2*A*–*D***).

Ten patients (45%) required changes in PEEP level by at least 4 cm H_2O (±) after pronation to reach maximum Crs (Fig. 2*A*). Patients in the Crs-unchanged and Crs-increased groups needed significantly lower

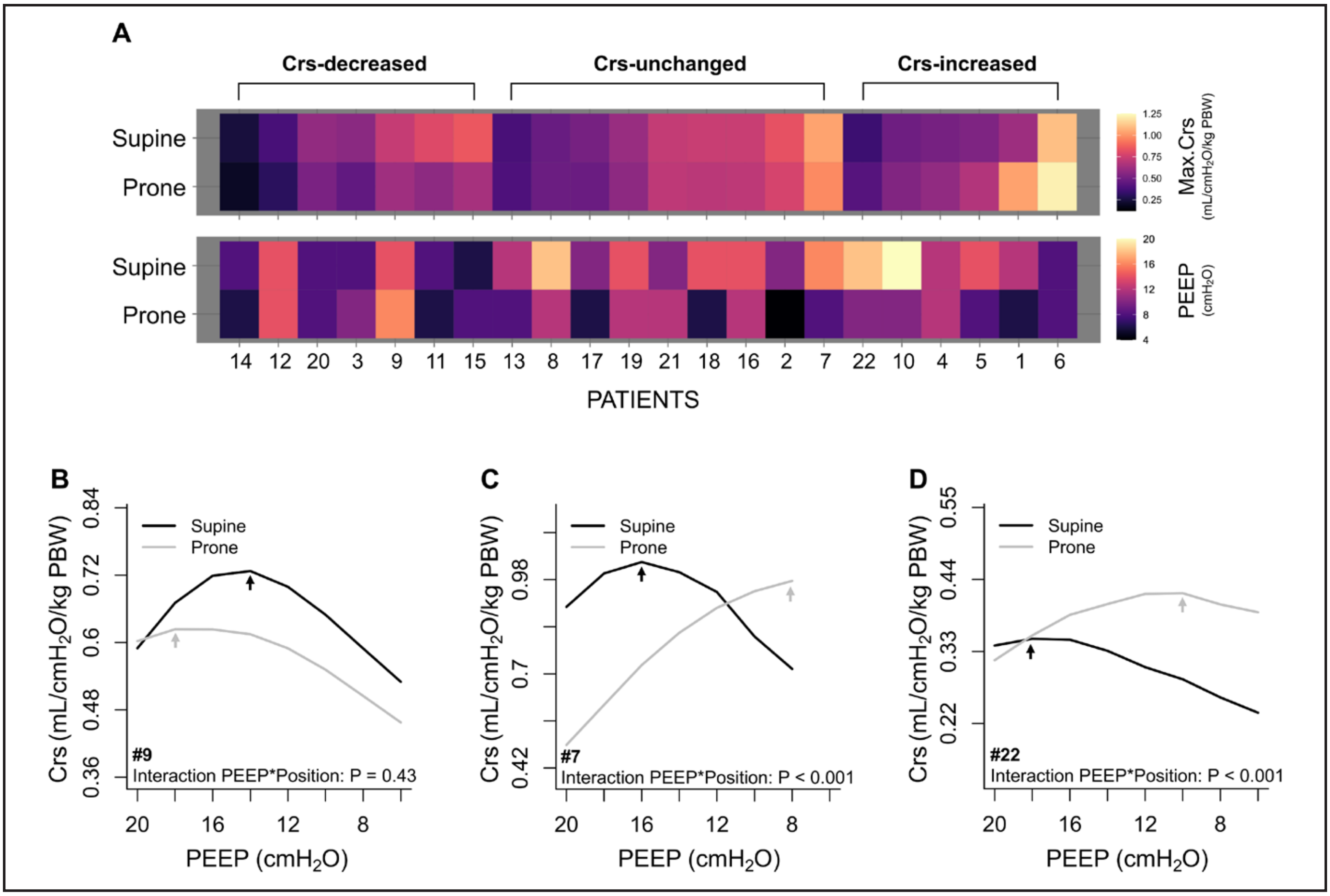

Figure 2. Effect of body position and positive end-expiratory pressure on respiratory mechanics. **A**, Heatmap visualization based on individual maximum respiratory system compliance (Crs; *top*) at the titrated positive end-expiratory pressure (PEEP; *bottom*) in supine and prone positions. *Columns*: patients grouped according to the changes in maximum Crs after pronation; *rows*: body position. *Color scale* indicates absolute values of Crs normalized by predicted body weight (PBW) and PEEP: *white*: highest value; *black*: lowest value. Note in the Crs panel that the color after pronation became lighter in six subjects, illustrating the increase in Crs (maximum compliance in prone position [$\text{Crs}_{\text{PRONE}}$]/maximum compliance in supine position [$\text{Crs}_{\text{SUPINE}}$] > 1.1), while changing to a *darker color* in seven subjects ($\text{Crs}_{\text{PRONE}}/\text{Crs}_{\text{SUPINE}} < 0.9$). PEEP was reduced by at least 4 cm H_2O in 45% of patients. **B**, **C**, and **D**, Changes in Crs in supine (*black line*) and in prone (*gray line*) positions during a decremental PEEP trial from three patients (numbers 9, 7, and 22) representing patients with maximum Crs decreased by more than 10% (B), did not change (C), and increased by more than 10% after pronation (D).

PEEP levels in prone position than supine position ($p < 0.05$, see **Fig. E5**, http://links.lww.com/CCX/B254). As a result of the PEEP reduction, six patients (66%) in the Crs-unchanged group demonstrated a decreased plateau pressure of greater than or equal to 4 cm H_2O (Fig. E5, http://links.lww.com/CCX/B254).

The body position significantly influenced the direction of change in Crs over a range of PEEP levels in half of our sample (Fig. 2*B*–*D*; and **Fig. E6**, http://links.lww.com/CCX/B254; $p < 0.05$ for interaction between body position and PEEP level). For example, in Figure 2*B*, Crs had an inverse relationship to PEEP levels below 16 cm H_2O; Crs was reduced in the supine position while increased in prone position.

When the titrated PEEP level in supine was applied in both positions, the median driving pressure increased by 1.6 cm H_2O (95% CI, 0.6–2.6) in prone compared with supine position (**Fig. E7*A***, http://links.lww.com/CCX/B254). Additionally, lung overdistension increased by 6.6% (95% CI, 2.7–10.6) in prone position compared with supine position (**Fig. E7*C*,** http://links.lww.com/CCX/B254). However, when the PEEPs that led to maximum compliance in each position were applied, the driving pressure and lung overdistension did not differ significantly between positions (**Fig. E7, *B*** and ***D***, http://links.lww.com/CCX/B254), suggesting the necessity to titrate PEEP if maximum Crs is the target postposition change.

Of those patients who underwent EM (n = 10), the median Ccw was lower in prone position compared with supine position (123 [100–132] mL/cm H_2O vs 149 [121–170] mL/cm H_2O, $p = 0.037$) (**Fig. E8**, http://links.lww.com/CCX/B254). Substantial reduction in Ccw postpronation was observed in subjects from the Crs-decreased group (patient 03: ΔCcw = –92 cm H_2O), Crs-unchanged (patient 02: ΔCcw = –70 cm H_2O) and Crs-increased (patient 01: ΔCcw = –63 cm H_2O). In a regression analysis, we observed that the changes in respiratory mechanics were better predicted by changes in lung mechanics ($R^2 = 0.84$, $p < 0.001$) but not by changes in chest wall mechanics ($R^2 = 0.09$, $p = 0.38$), suggesting that we cannot generalize that a significant reduction in Crs postpronation is consistently related to the Ccw reduction.

Changes in Regional Ventilation

For patients in the study, approximately 50–60% of tidal volume remained preserved in the central region of the lung despite body positioning and PEEP levels (**Fig. E9**, http://links.lww.com/CCX/B254). The ventilation distribution increased progressively in the ventral region in supine and in the dorsal region in prone, both nondependent zones, over the decrease of PEEP (Fig. E9, http://links.lww.com/CCX/B254).

While in the supine position with titrated PEEP, the ventilation distribution disparity between the dorsal and ventral regions (dorsal–ventral) is negligible (< 5%), indicating a uniform distribution of ventilation (**Fig. 3**). However, following pronation, the discrepancy in dorsal–ventral ventilation intensifies among the Crs-decreased to Crs-increased group, implying that the prone position might cause heterogeneous ventilation distribution in patients with increased Crs after pronation (Fig. 3, $p = 0.01$).

The predominance of dorsal ventilation in prone positioning in the Crs-increased group may occur due to the combination of significant dorsal lung recruitment as well as onset of ventral atelectasis, as illustrated in **Figure E10** (http://links.lww.com/CCX/B254).

Changes in Regional Mechanics

In both positions, the reduction of PEEP led to an increase in regional compliance in nondependent regions and a decrease in dependent regions (**Fig. E11**, http://links.lww.com/CCX/B254). Patients in the Crs-decreased group demonstrated a minimal increase in dorsal compliance after pronation, which was insufficient to counteract the decrease in ventral compliance (**Fig. 4**; and Fig. E11, http://links.lww.com/CCX/B254). In patients with unchanged Crs, there was a similar proportion of an increase in dorsal compliance and a decrease in ventral compliance when they were positioned in prone position receiving titrated PEEP (Fig.4; and Fig. E11, http://links.lww.com/CCX/B254).

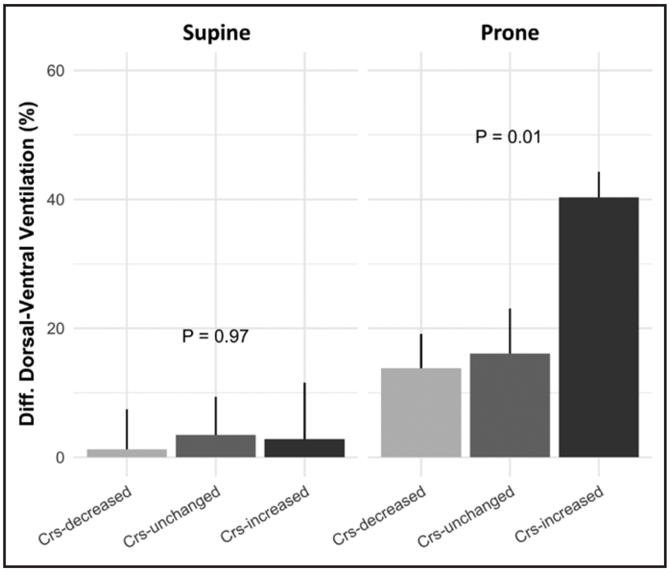

Figure 3. Difference of ventilation distribution between dorsal and ventral regions in supine and prone positions based on maximum compliance in prone position/maximum compliance in supine position ratio groups at titrated positive end-expiratory pressure leading to maximum respiratory system compliance (Crs) in each position. On average, in prone position, the ventilation distribution in the dorsal region was 40% higher than in the ventral region within the Crs-increased group.

Finally, patients in the Crs-increased group showed a significant increase in dorsal compliance and a minor proportion reduction in ventral compliance reduction after pronation (Fig. 4; and Fig. E11, http://links.lww.com/CCX/B254). This result suggests that the magnitude of changes in ventral and dorsal compliance may significantly drive global Crs after pronation.

The pressure–volume curve method detected a significant increase in dorsal compliance only for those in the Crs-increased group (**Fig. 5**, $p < 0.001$ for the difference between body positions). Furthermore, in all groups in supine position, the pressure–volume curve of the dorsal region followed a positive exponential growth, indicating that very high PEEP levels are needed to initiate dorsal recruitment (Fig. 5). In contrast, in prone position, any PEEP higher than 10–12 cm H_2O reduced the slope of the

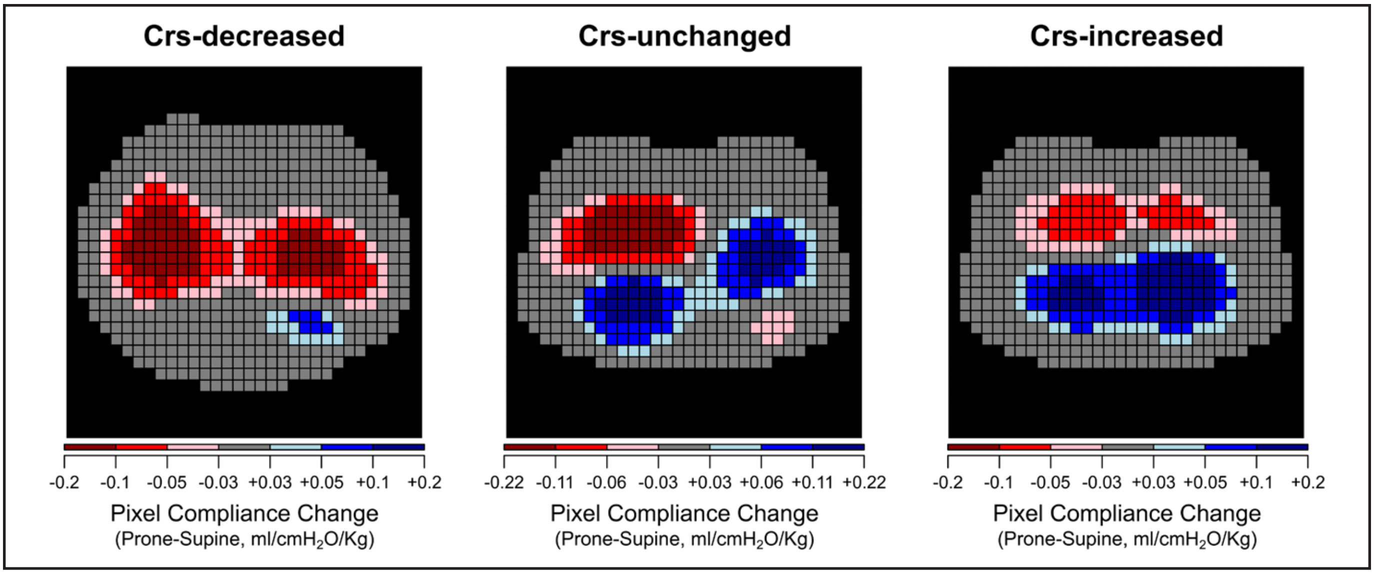

Figure 4. Pixel compliance change after pronation (prone-supine) from representative patients in the respiratory system compliance (Crs)-decreased, Crs-unchanged, and Crs-increased groups. The *color scale* refers to compliance change in milliliters per centimeter H_2O/kg of predicted body weight. *Blue* indicates pixels with increased compliance; *red* indicates pixels with decreased compliance. Spatial orientation of the electrical impedance tomography image: the right side of the chest is located to the *left of the image* and the anterior region at the *top of the image*.

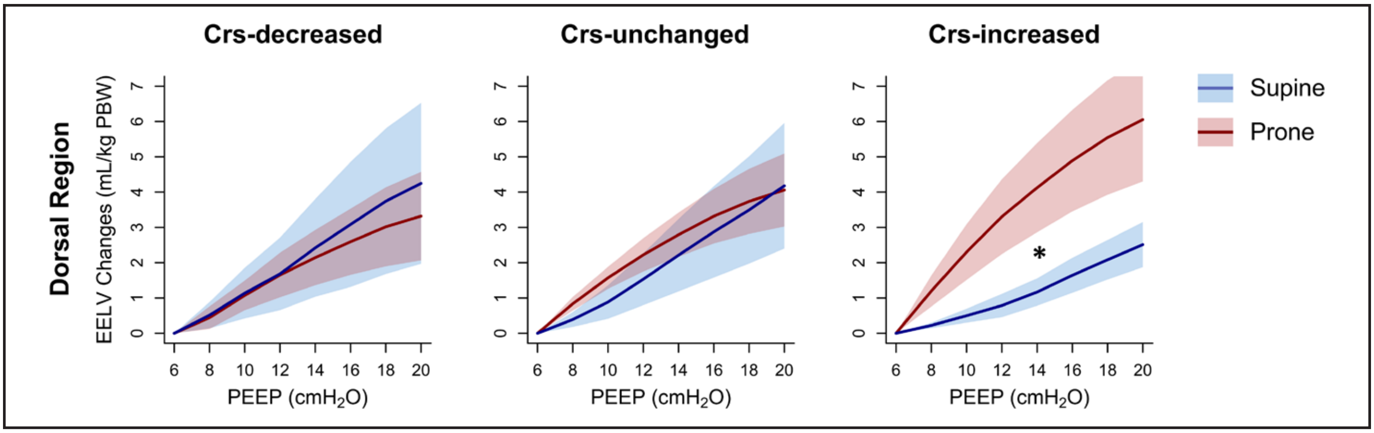

Figure 5. Pressure vs end-expiratory lung volume (EELV) curves in the dorsal region stratified by maximum compliance in prone position/maximum compliance in supine position ratio groups. Changes in EELV were quantified during the decremental positive end-expiratory pressure (PEEP) trial in supine and prone positions and are relative to EELV measured at PEEP of 6 cm H_2O in each position. *$p < 0.001$ for the difference between body positions. Crs = respiratory system compliance. PBW = predicted body weight.

dorsal pressure–volume curve, suggesting progressive deterioration of regional compliance due to overdistension (Fig. 5). A progressive reduction in the slope of ventral region pressure–volume curve was also detected in all groups in the supine position (**Fig. E12**, http://links.lww.com/CCX/B254).

DISCUSSION

This physiologic study in patients with ARDS demonstrated a variety of responses in global and regional mechanics induced by prone position: 1) there is a maximum Crs change in most patients (59%), whether Crs increased or decreased, after proning and PEEP titration. Even in those patients for whom maximum Crs does not change, plateau pressure might change dramatically after proning and PEEP titration and 2) regional dorsal ventilation and compliance did not show a consistent change in the entire sample, increasing significantly only in a subgroup of subjects with increased Crs postpronation.

These results provide new insight into how respiratory mechanics can change after pronation in relation to a range of PEEP levels (9–11). Indeed, several previous studies in ARDS characterized respiratory mechanics in supine and prone positions and PEEP levels between supine and prone were unchanged (4, 12–14). Up to now, the lack of regional ventilation assessment at bedside and data testing Crs over a wide range of PEEP limited the physiologic assessment of the effect of prone positioning on Crs. The largely unpredictable and variable responses to proning that we observed suggest that an overall averaging of changes in global Crs across a prone study population might negate individual responses.

We performed EIT in our study cohort to describe the intraindividual regional heterogeneity of responses after proning. We demonstrated in prone position a progressive increase in dorsal ventilation over the decrease of PEEP, which could be interpreted as the release of regional overdistension. But, combined with regional compliance data, we detected that prone position significantly increased dorsal compliance (by quasi-static and dynamic methods), specifically in the Crs-increased group, suggesting that the ventilation change might also be associated with a significant regional lung recruitment. Although there is a suggestion of almost complete atelectasis in the ventral lung in the Crs-increased group after pronation, the overall influence of the ventral region seems small compared with the increased dorsal lung mechanics.

The heterogeneous response on dorsal mechanics to prone position is possibly explained by the variety of morphological lung features in patients with ARDS (19, 20). Therefore, patients with focal dorsal ARDS may present a higher chance of improving dorsal mechanics postpronation than those with nonfocal ARDS. In contrast, animal ARDS models are highly reproducible to present gravitational dorsal lung injury when lung lavage is performed only in the supine position and to describe a consequent improvement in dorsal mechanics postpronation. Thus, previous descriptions with ARDS models may represent just a portion of ARDS patients with high recruitability.

Our findings indicate that proning does not homogenize the ventilation distribution in the lung; rather, ventilation is regionally redistributed according to lung geometry along a gravitational gradient. These results confirm early CT imaging studies by Langer et al (21) showing the intraindividual heterogeneous responses of patients when prone. The substantial restoration of dorsal lung volumes may provide an overall lower tidal strain and thus better lung protection in prone position for the Crs-increased group (22). The improved lung protection might be attributable to the improved global maximum Crs after proning suggesting that proning recruits portions of lung that high airway pressures cannot access in supine position.

In the present study, oxygenation improved after pronation, probably due to improvement in ventilation–perfusion matching (5–8), regardless of the Crs response. At the bedside, clinicians look for changes in oxygenation after pronation to classify patients as “responders” or “nonresponders” to proning. The oxygenation “target” may explain why clinicians may favor to reduce FIO_2 rather than PEEP once oxygenation improves in prone position (4, 12, 14). However, with the improved oxygenation conferred by proning, lower PEEP levels may be better tolerated, which could theoretically facilitate the relief of lung overdistension, minimizing high driving pressure (Fig. E7, http://links.lww.com/CCX/B254). From a “mechanical” perspective, approximately 30% of our patients showed a “positive response” with an increase of maximum Crs after pronation, suggesting a likelihood of reduced risk of mortality secondary to a decreased driving pressure (9, 23, 24).

On the contrary, patients in the Crs-decreased group may present significant deterioration in lung compliance and chest wall. According to previous data in ARDS patients (13, 25–27), the average reduction in Ccw after pronation may decrease Crs by 3–8% (**Table E2**, http://links.lww.com/CCX/B254). Therefore, we believe that subjects with reduced Crs greater than 10% postpronation may benefit from advanced EM monitoring to better understand the chest wall contribution.

The main limitations of this physiologic study are: 1) the small sample size, this study is not powered to test the relationship between lung mechanics response and survival; and 2) the potential influence of the chest wall component on unexplained alterations in respiratory mechanics might have been a factor. Although a subset of patients underwent EM monitoring, more studies are needed to definitively detail chest wall components relative to lung recruitment; 3) EIT regional ventilation and compliance may overestimate lung recruitment. The increase in regional compliance assessed by EIT may incorporate both the recruitment of lung areas (i.e., nonaerated lung becoming aerated) and just improvement in alveoli compliance (i.e., alveoli poorly aerated become normally aerated); and 4) our study assessed a portion of the physiologic effects on lung mechanics induced by prone position. The significant impact of prone position on survival described by RCTs may not be only related to increased dorsal compliance. This study did not measure other mechanisms like lung strain and cyclic opening-closing.

Strengths include the prospective collection of detailed data with individual assessments of global and regional respiratory mechanics over a wide range of PEEP levels from two academic centers. We believe that unveiling the individual mechanical response to body position and PEEP may help providers tailor treatment and optimize lung function and lung protection in specific patients. The physiologic data presented may let future trials aiming to assess the benefits of titrated PEEP levels during prone ventilation and establish the impact of the regional mechanics change in clinical outcomes.

CONCLUSIONS

Most patients with ARDS showed modifications in maximum Crs after pronation. In addition, dorsal lung ventilation and compliance did not consistently change across our sample of patients from supine to prone position. Patients who experienced a decrease in maximum Crs after pronation showed minimal changes in ventilation and compliance in the dorsal region of the lungs. On the other hand, patients who had an increase in Crs after pronation had higher dorsal compliance and exhibited the most heterogeneous distribution of ventilation between the ventral and dorsal regions in the prone position compared with the supine position.

These findings suggest that changes in regional mechanics have a significant impact on global compliance after pronation and challenge the previous belief that pronation consistently leads to more uniform regional lung mechanics. This result suggests the need to assess the regional lung function individually to establish the body positioning mechanical effect.

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Drs. Morais, Alcala, and Santis Santiago contributed equally.

Drs. Morais, Alcala, Costa, Amato, and Berra conceived and designed the study. Drs. Morais, Alcala, Santis Santiago, Valsecchi, Diaz, Wanderley, Fakhr, Di Fenza, Gianni, Costa, Amato, and Berra collected the data. Drs. Morais, Costa, and Berra conducted the data analysis. Drs. Valsecchi, Diaz, Wanderley, Fakhr, Di Fenza, Gianni, Foote, Bittner, and Carroll made critical revisions and intellectual contributions. Drs. Morais, Alcala, Santis Santiago, and Berra prepared the first draft of the article, and all authors revised the draft. All authors gave final approval of the article version to be published.

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